DEVELOPMENT OF METHOD OF TEST FOR CONCRETE MIXER PERFORMANCE

TECHNICAL REPORT NO. 6-562

March 1961

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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PREFACE

This investigation was authorized by the Office, Chief of Engineers, in first indorsement, dated 12 November 1958, to a letter from the U. S. Army Engineer Waterways Experiment Station, dated 16 October 1958, subject, "Revised Project Plan for Development of a Test for Concrete Mixer Performance," and is a part of CWI Item 616, "Performance of Construction Plant and Equipment," of the Civil Works Investigation Program of the Corps of Engineers.

The investigation was conducted in the Concrete Division, Waterways Experiment Station, during fiscal year 1959, under the direction of Messrs. Thomas B. Kennedy, James M. Polatty, and William O. Tynes. This report was prepared by Messrs. Tynes and Kenneth L. Saucier. Col. Edmund H. Lang, CE, was Director of the Waterways Experiment Station during this investigation and the preparation of this report. Mr. J. B. Tiffany was Technical Director.

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SUMMARY

A literature survey revealed that considerable work had been done toward the development of methods of testing for determining the efficiency of concrete mixer performance. However, it was believed that a reliable and suitable test method that could be used both in the laboratory and at field installations did not exist. Therefore, this investigation was undertaken to evaluate various test methods and to develop a satisfactory method for determining whether a concrete mixer is blending the concrete mixture into a homogeneous mass.

The investigation was divided into five phases, four laboratory and one field. In the laboratory phases, concrete mixtures containing 1-1/2- and 6-in. maximum size aggregates were mixed in a 10-S Koehring mixer for various lengths of time to simulate well-mixed and poorly mixed concrete; in the field phases, mixtures containing 6-in. aggregate were mixed in a standard 2-cu-yd-capacity Koehring mixer to simulate well-mixed and poorly mixed concrete. It was found that three samples from each batch were an adequate number for testing.

Results indicated tests to determine (a) unit weight of air-free mortar, (b) percentage of coarse aggregate in the concrete, (c) water content of fresh mortar, and (d) cement content of dry mortar to be the most reliable and suitable for evaluating concrete mixer performance. Maximum allowable variations were established for each test.

The proposed test method for evaluating concrete mixer performance developed from this investigation is included as Appendix A.

DEVELOPMENT OF METHOD OF TEST FOR CONCRETE MIXER PERFORMANCE

PART I: INTRODUCTION

Background and Purpose of Investigation

1. A search of the available, pertinent literature (references 1-4, 6-15, 18-21 of the Bibliography) was made before the investigation reported herein was begun, and revealed that considerable work had been done toward development of test methods for evaluating the performance of concrete mixers. These methods included tests to determine strength of hardened concrete specimens, unit weight of the freshly mixed concrete, chemical analysis for cement content, sieve analysis to determine the constituent parts of a mixture, and unit weight of the air-free mortar. Correlation between tests is inherently difficult; however, information found in the literature formed the basis for a portion of the work performed in this investigation.

2. At the beginning of the investigation, it was felt that no reliable and suitable test method existed for evaluating concrete mixer performance both in the laboratory and at field installations. Therefore, the purpose of this study was to evaluate various test methods and develop a satisfactory one for determining whether a concrete mixer is blending the concrete mixture components into a homogeneous mass. The results of this investigation were to form the basis for a standard test method to be included in the Handbook for Concrete and Cement[17*] as CRD-C 55, and were also to assist in establishing the requirements for mixer performance and mixing time to be included in Corps of Engineers Guide Specifications.

Scope of Study

3. The investigation was conducted in five phases: phases I, II, III, and V were performed in the laboratory and phase IV in the field. The concrete mixtures used in the laboratory phases were mixed in a 10-S

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* Raised numbers refer to similarly numbered entries in the Bibliography at end of the main body of this report.

Koehring, closed-end, rocking-tilting mixer, and those in the field phase were mixed in a standard 2-cu-yd Koehring tilting mixer. The tests used to evaluate the performance of the mixer were those for air content and unit weight of the concrete, mortar:coarse aggregate ratio, unit weight of air-free mortar, percentage of cement by weight of dry mortar, water content of fresh mortar, and percentage of coarse aggregate in sample. The scope of each phase was as follows:

a. Phase I consisted of tests of both well-mixed and poorly mixed concrete containing 1-1/2-in. maximum size aggregate to select test properties for use in evaluating concrete mixing, to determine the normal variations that occur in these properties in well-mixed concrete, and to establish the minimum number of samples required per batch for determining the adequacy of mixing.

b. Phase II consisted of tests of concrete containing 1-1/2-in. maximum size aggregate mixed for arbitrarily selected mixing times to develop and evaluate test methods that would indicate the degree of mixing.

c. Phase III consisted of tests of both well-mixed and poorly mixed concrete containing 6-in. maximum size aggregate (mixed in the 10-S Koehring mixer), employing the tests selected for evaluation in phases I and II.

d. Phase IV consisted of tests of both well-mixed and poorly mixed concrete containing 6-in. maximum size aggregate mixed in the 2-cu-yd Koehring mixer.

e. Phase V consisted of cement-content tests of concrete, containing 1-1/2- and 6-in. maximum size aggregate and having various cement factors, using revised test procedures for comparison with results of similar tests in which the original procedures were used.

PART II: MATERIALS, MIXTURES, SAMPLING EQUIPMENT, AND PROCEDURES

Materials

4. The materials used in this investigation were Type II portland cement, neutralized Vinsol resin solution, and manufactured fine and coarse limestone aggregates.

Mixtures

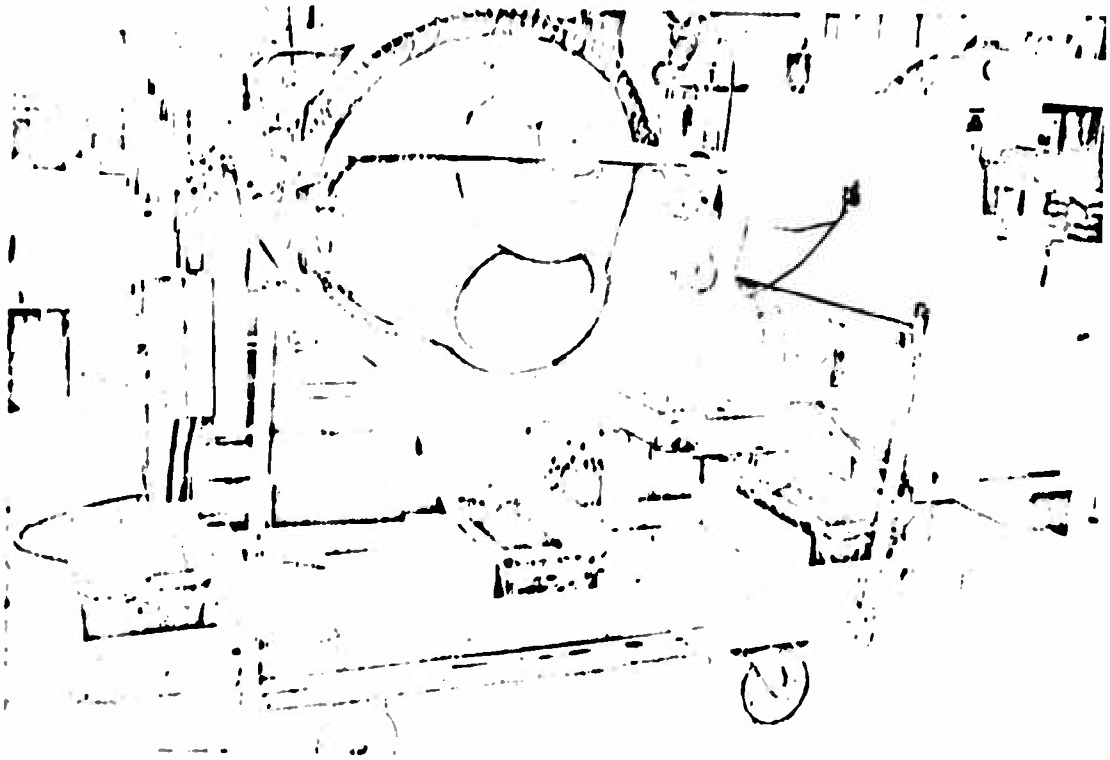
5. Two concrete mixtures were used in phases I-IV of this investigation, one containing 1-1/2-in. and the other 6-in. maximum size aggregate, with cement factors of 5.5 and 2.5 bags per cu yd, respectively. Only the mixing time was varied to provide so-called well-mixed and poorly mixed concrete. Six additional mixtures, similar to these except for cement contents, were used in phase V.

Sampling Equipment

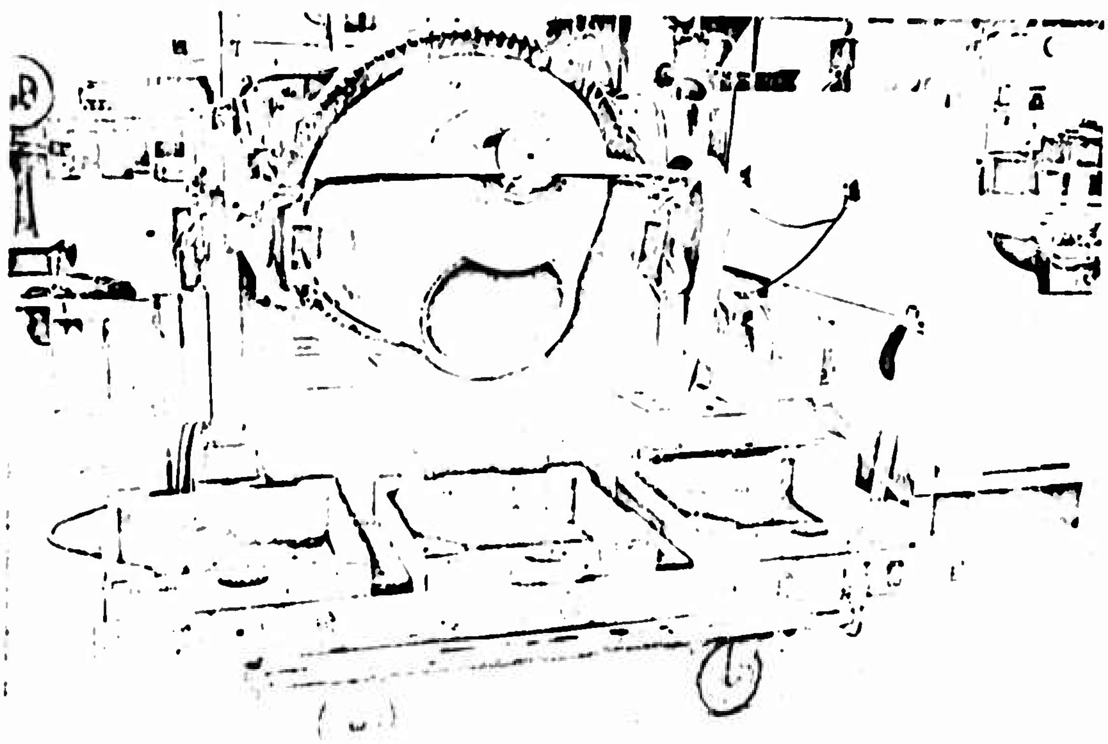
6. In all the laboratory phases a compartmented sampler, mounted on wheels, was used to obtain samples as the concrete was being discharged from the mixer. In the first part of phase I a five-compartment sampler was used; in all of the other laboratory tests a three-compartment sampler was used. For the 1-1/2-in. maximum size aggregate concrete tests the sampler setup shown in fig. 1a was used for obtaining three 0.75-cu-ft samples. Fig. 1b shows the sampler setup used in the 6-in. maximum size aggregate concrete tests to obtain three 2-cu-ft samples.

7. For the field tests a columnar sampler, 25 in. by 30 in. by 14 ft, capable of holding 2 cu yd of concrete and of being tilted from a vertical to a horizontal position, was constructed and installed immediately beneath the discharge hopper of the field mixing plant. Fig. 2 shows the sampler in a vertical position.

Fig. 2. Columnar sampler used to obtain three 6-cu-ft samples of 6-in. maximum size aggregate concrete in the field tests



a. Sampler setup for obtaining three 0.75-cu-ft samples of 1-1/2-in. maximum size aggregate concrete



b. Sampler setup for obtaining three 2-cu-ft samples of 6-in. maximum size aggregate concrete

Fig. 1. The 10-S Koehring closed-end rocking-tilting mixer and three-compartment sampler used in the laboratory tests

Procedures

Sampling

8. In all of the laboratory tests (phases I, II, III, and V) the wheeled, compartmented sampler was passed through the discharge stream of the mixer to obtain samples representing the first, middle, and last portions of the batch as discharged.

9. To obtain the samples in the field (phase IV), the columnar sampler was placed in a vertical position and the entire batch of concrete was discharged into it. The top cover was then secured and the sampler tilted from a vertical to a horizontal position. The side door was then opened and three samples were obtained, each consisting of approximately 6 cu ft (1000 lb) of concrete, one from the middle and one from each end of the sampler, representing the first, middle, and last portions of the batch as discharged. The samples were obtained by taking a complete cross section, approximately 18 by 30 in., through the concrete in the sampler (fig. 3).

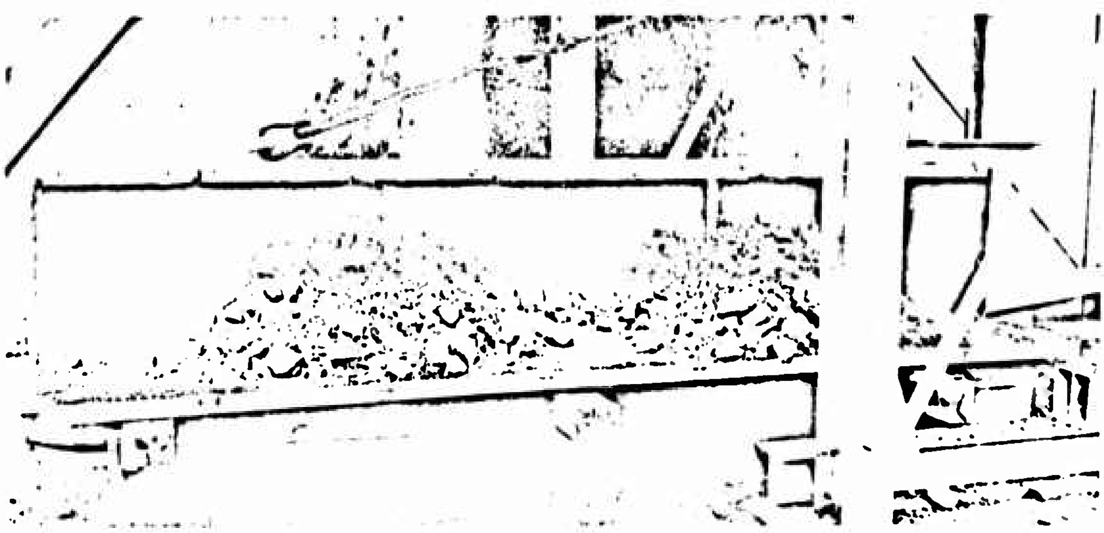


Fig. 3. Columnar sampler in horizontal position with side door open, after three 6-cu-ft samples had been removed

Test methods

10. Test methods conformed in general to those found in the Handbook for Concrete and Cement;[17] those not included in the Handbook are described in Appendix A to this report, except that for phases I through IV the cement-content test procedures for grinding the mortar sample and washing

the low-specific-gravity solids from the centrifuge tube differed slightly from those described in Appendix A as explained in the discussion of phase V (paragraphs 24-26).

PART III: TESTS AND RESULTS

Phase I, Laboratory Tests to Select Tests and Number of Samples for Evaluating Concrete Containing 1-1/2-in. Maximum Size Aggregate

Tests of well-mixed concrete

11. The results reported in the literature[1-4,6-15,18-21] indicated that certain tests might be of value in evaluating the performance of a concrete mixer. Among these were tests to determine air content and unit weight of the concrete, mortar:coarse aggregate ratio, unit weight of air-free mortar, and weight of coarse aggregate in the sample. All of these were used in the phase I tests of what was considered to be well-mixed concrete. Ten batches of concrete were proportioned and mixed for 240 sec, and five samples were taken in alphabetical order, A through E, from each batch. These samples were tested in random order so that it was possible to differentiate between differences due to sampling order and those due to time of testing. The results were analyzed by the analysis of variance method to determine whether time of testing had an effect and whether the laboratory mixer was free of systematic differences among sequential samples.

12. Results of all of the tests mentioned above are given in table 1 with the exception of the weight of coarse aggregate in the air-content container which has, in table 1, been converted to per cent coarse aggregate. The results of the analysis of variance,[5] based on the five samples from each of the 10 batches, are as follows:

Effect of Differences in	Test	Ratio: Calculated Variance	Ratio: Required for 99%*	Ratio: Required for 95%*	Conclusion
Batches	Air content	26.31	3.06	--	Very significant
	Unit weight of concrete	24.91	3.06	--	Very significant
	Mortar:coarse aggr ratio	2.53	3.06	2.21	Significant
	Unit wt, air-free mortar	13.09	3.06	--	Very significant
	Wt of coarse aggr	1.75	3.06	2.21	Not significant

(Continued)

* Confidence limits.

Effect of Differ-ences in	Test	Ratio: Calculated Variance	Ratio: Required for 99%	Ratio: Required for 95%	Conclusion
Times of testing	Air content	7.36	4.02	--	Very significant
	Unit weight of concrete	7.18	4.02	--	Very significant
	Mortar:coarse aggr ratio	4.32	4.02	--	Very significant
	Unit wt, air-free mortar	6.99	4.02	--	Very significant
	Wt of coarse aggr	3.51	4.02	2.69	Significant
Samples	Air content	19.63	4.02	--	Very significant
	Unit weight of concrete	19.71	4.02	--	Very significant
	Mortar:coarse aggr ratio	6.52	4.02	--	Very significant
	Unit wt, air-free mortar	1.85	4.02	2.69	Not significant
	Wt of coarse aggr	7.91	4.02	--	Very significant

The analysis demonstrated a number of interesting facts concerning the batching, mixing, and time of testing. The effect of time on all tests is apparent; hence it is important that, whatever tests are selected, they be conducted with as little time lag as possible. In all comparisons the variance ratios for air content and unit weight agree closely; this suggests that variation in unit weight is almost entirely due to variation in air content. Nearly the same agreement exists for mortar:coarse aggregate ratio and weight of coarse aggregate. This is not surprising since the two tests measure essentially the same property. The among-batch variance ratios indicate very significant differences not only in air content and unit weight but also in unit weight of air-free mortar, whereas differences in weight of coarse aggregate and mortar:coarse aggregate ratio are not significant or barely significant. The first two indicate the difficulty of precise batch-to-batch air-content control; the latter three suggest that the weighing is accurate but that variation in sand moisture produces variation in mortar properties. The among-sample variance ratios indicate that there are systematic differences among samples from the same batch for all properties tested except for unit weight of air-free mortar.

13. Selection of evaluation tests. Among the tests studied above, air content and unit weight of concrete do not seem well adapted to the purpose. Because of the lack of control of these quantities even in well-mixed concrete, it would be difficult to set meaningful limits. There is no reason to select both the mortar:coarse aggregate ratio and weight of coarse aggregate since they are so closely related. The latter was adopted

but modified to a per cent by weight rather than a weight per unit volume basis. This modification was made because of the difficulty in securing test samples of identical size, particularly for concrete containing the larger size aggregate. In order to obtain more complete information about the contents of a sample, two additional tests were included. The cement-content test was selected since it is not influenced by the time required to complete the test after sampling, and the water-content test was selected since it can be run almost simultaneously for all samples. Thus, these four tests, unit weight of air-free mortar, percentage of coarse aggregate, cement content, and water content of mortar, should provide a basis for evaluating mixer performance relatively free from the complicating influence of time.

14. Determination of required number of samples. At the start of this investigation, information was not available as to the number of samples required to properly evaluate the performance of a mixer, and a five-sample group was selected as a starting point. It was felt that the testing of more than five samples from any one batch would require too much time to be acceptable under field conditions. After the testing of the ten batches using the five-samples-per-batch procedure, a study was made to investigate the possibility of reducing the number of samples required to three. These data are also shown in table 1. From the maximum variations for unit weight of air-free mortar and percentage of coarse aggregate, it is apparent that the three-sample values are comparable to the five-sample values. Therefore, the three-sample procedure, consisting of taking samples from the first, middle, and last portions of the mixer discharge, was considered to be as good as the five-sample procedure, and was used for the remainder of this investigation. Considering only the results determined on three-sample groups, the normal variation within batch for the unit weight of air-free mortar and percentage of coarse aggregate was established as the average variation plus two standard deviations for well-mixed concrete as shown below.

Test Property	Average Variation ($\bar{x}$), %	Standard Deviation (S), %	$\bar{x}$ + 2S	Upper Limit Selected, %
Unit weight of air-free mortar	0.276	0.174	0.624	0.7
% coarse aggregate	2.04	0.82	3.68	4.0

The percentage variation for the unit weight of air-free mortar and percentage of coarse aggregate was determined by dividing the maximum difference of the three test values from their average by their average, and these values should not vary more than 0.7 and 4.0%, respectively. These variation limits agree closely with those recommended by the Bureau of Reclamation[21] of 0.8 and 5.0%.

Corroboration tests
of poorly mixed concrete

15. Six additional batches of concrete were mixed for 15 sec (representing poor mixing) and tested to see if their properties fell outside the proposed limits. Three samples were obtained from each batch, and were tested for the same properties as the well-mixed concrete, including unit weight of air-free mortar and percentage of coarse aggregate. The results of these tests are shown in table 2. Based on the test criteria selected for evaluating mixer performance, these data indicate that the unit weight of air-free mortar would disqualify this time of mixing in every test, since the variation was greater than 0.7% in all tests. However, the percentage of coarse aggregate would disqualify this mixing time in only 67% of the test batches, since the maximum variation exceeded 4.0% in four of the six tests.

Phase II, Laboratory Tests to Develop and Evaluate Test Methods for Concrete Containing 1-1/2-in. Aggregate

16. Utilizing the test methods selected in phase I, and other tests necessary for measuring the distribution of the mixture ingredients, several batches were made and tested at different mixing times. Since it is assumed that the ingredients of well-mixed concrete are reasonably well distributed, then one can be reasonably certain that the concrete is well mixed if tests indicate uniform unit weight of air-free mortar and uniform percentages of coarse aggregate, water, and cement between samples.

17. Twenty-four batches of concrete containing 1-1/2-in. aggregate were mixed in the 10-S Koehring mixer in phase II, six each for mixing times of 45, 90, 150, and 240 sec. Each batch was sampled after mixing and tested for the four characteristics mentioned in paragraph 16. (It will be

noted that two determinations of percentage of coarse aggregate were made, one based on the air-content test container sample as in previous tests, and the other on the total sample to determine whether use of a large sample would reduce sampling error. Results shown in table 3 indicate that both sample sizes were satisfactory.)

18. In the following analyses of results of mixing-time tests, all the data from concrete batches mixed 240 sec in phases I and II were combined to provide a better basis for establishing permissible variations in unit weight of air-free mortar and percentage of coarse aggregate than those provided by phase I alone. Again the normal variation within batch was established as the average variation plus two standard deviations, as shown below.

Test Property	Average Variation ($\bar{x}$), %	Standard Deviation (S), %	$\bar{x}$ + 2S	Upper Limit Selected, %
Unit weight of air-free mortar	0.33	0.19	0.71*	0.8
% coarse aggregate	2.33	0.85	4.03**	5.0

* The test range for the unit weight of air-free mortar was 0.624 to 0.835%, and it was felt that 0.8% should be the upper limit. This is the limit permitted by the Bureau of Reclamation.

** The test range for the percentage of coarse aggregate was 4.24 to 4.44%, and it was felt that the limit should be 5% as permitted by the Bureau of Reclamation.

19. Since no water-content or cement-content tests were made in phase I, the limits selected for these two properties are based on the data developed from the batches mixed 240 sec in phase II. Again the relation used to set limits was the average variation plus two standard deviations, as shown below.

Test Property	Average Variation ($\bar{x}$), %	Standard Deviation (S), %	$\bar{x}$ + 2S	Upper Limit Selected, %
Water content	1.92	1.30	4.52	5.0
Cement content	6.96	2.52	12.00	12.0

The limits of 5.0% for water content and 12.0% for cement content were selected on the basis of these data. (The cement-content limit was later changed to 10% when the test method for determination of cement content was revised for the phase V tests; see paragraph 26.)

20. Applying the limits on maximum variation of 0.8% for air-free density, 5.0% for coarse aggregate, 5.0% for water content, and 12.0% for cement content to the three samples from each of the six batches tested, the number of batches tested in phase II that would be within these limits are:

No. of Batches Tested	Mixing Time sec	Number of Batches Falling Within Selected Limits: Concrete: Unit Weight of Air-Free Mortar	Concrete: Percentage of Coarse Aggregate	Water Content of Fresh Mortar	Cement Content of Dry Mortar
6	45	0	0	0	1
6	90	4	6	3	5
6	150	6	6	6	6
6	240	6	6	6	6

These data indicate that with this particular mixer (the 10-S Koehring), using these test limits, it is necessary to mix a batch 150 sec in order to obtain well-mixed concrete. The 90-sec mixing time produced borderline concrete.

Phase III, Laboratory Tests of Suitability of Evaluation Tests for Concrete Containing 6-in. Maximum Size Aggregate

21. Twelve batches of 6-in. maximum size aggregate concrete were proportioned and mixed in the 10-S mixer, six for 15 sec and six for 240 sec. From each batch three samples of approximately 2 cu ft were taken and tested. Results of these tests are shown in table 4. Using the phase II limits given in paragraphs 18 and 19 and an additional 13% limit (as determined in phase III, see paragraph 22), for percentage of coarse aggregate, the number of batches that would be within these limits are:

No. of Batches Tested	Mixing Time sec	Number of Batches Falling Within Selected Limits: Unit Weight of Air-Free Mortar	Percentage of Coarse Aggregate: 5% Limit	Percentage of Coarse Aggregate: 13% Limit	Water Content of Fresh Mortar	Cement Content of Dry Mortar
6	15	1	1	4	1	1
6	240	6	2	6	6	5

22. The maximum variations set for the 1-1/2-in. maximum size aggregate concrete in phases I and II appear to be satisfactory for the 6-in. aggregate concrete except possibly for the percentage of coarse aggregate. The maximum variation of 5% previously set for this test property would have to be increased to allow all of the batches mixed 240 sec to be within the limits, and using the method of the average variation plus two standard deviations for these six batches, the limit would become 13%. This increase may be due to the size of sample (2 cu ft), or to the small batches used in the 10-S mixer, or most probably to the mixer not being suitable for use with 6-in. aggregate.

Phase IV, Field Tests of Suitability of Evaluation Tests for Concrete Containing 6-in. Maximum Size Aggregate

23. In this field phase of the investigation, nine batches of concrete containing 6-in. maximum size aggregate were proportioned and mixed in the 2-cu-yd mixer. Three batches were mixed for 15 sec, supposedly representing a poorly mixed concrete; three were mixed for 120 sec, representing a standard mixed concrete; and three for 240 sec, supposedly representing an excessively mixed concrete. The results of these tests are shown in table 5. The number of these batches that would be within the limits given in paragraph 20 are:

		Number of Batches Falling Within Selected Limits			
		Concrete		Water	Cement
No. of Batches Tested	Mixing Time sec	Unit Weight of Air-Free Mortar	Percentage of Coarse Aggregate	Content of Fresh Mortar	Content of Dry Mortar
3	15	0	0	0	0
3	120	3	2	3	1
3	240	3	3	3	3

The maximum variations of the batches mixed for 240 sec are within the previously established limits, which indicates that these data are comparable to the laboratory data obtained in phases I and II. Two of the batches mixed for 120 sec exceeded the limits for cement content, and one exceeded that for percentage of coarse aggregate. It is to be noted that the percentage of coarse aggregate values for two of the batches mixed for

120 sec and all of the batches mixed for 240 sec are within the 5% limit established for 1-1/2-in. maximum size aggregate concrete in phases I and II. It is believed that the lower values secured in the phase IV field tests compared with the 13% limit determined in the phase III laboratory tests of 6-in. aggregate concrete are probably due to the difference in size and design of the two mixers.

Phase V, Revised Cement-Content Test

Revisions

24. Although it was realized that care and time are necessary to obtain accurate results in the cement-content test, it was still felt that this test should be part of the mixer performance evaluation. Therefore an extensive study was made of the procedures used previously in the cement-content test in an effort to find means of improving its reproducibility. From this study the recommended method outlined in Appendix A was developed.

25. Two revisions in the original cement-content test procedures are incorporated in the recommended method. First, it was found in the sieve-grinding operation used to increase the fineness of the dry concrete and sand prior to centrifuging that when the mortar was ground fine enough to pass the No. 30 sieve used in the original test method, some fine material was manufactured which did not properly separate in the heavy media. When a No. 16 sieve was substituted for the No. 30 sieve, the amount of extremely fine material was decreased, and the test results appeared to be more reproducible. Second, it was noticed that in the acetone washing of the floating materials taken from the centrifuge tube, the material never settled out of the wash in less than about 20 sec. Therefore it was thought that the variable settling time permitted by the original method caused different degrees of settling, and that a definite settling time should be established in order to secure optimum separation. By experimentation it was found that more reproducible results could be obtained using the settling times specified in Appendix A.

Tests using revised method

26. Eight batches of concrete were proportioned with two maximum

size aggregates (1-1/2 and 6 in.) and with varying cement factors, and were mixed in the laboratory 10-S mixer. Results of tests on three samples of each batch (table 6) indicate an improvement in the test method as compared with results obtained in phases II and III. It is felt that the computed variation of 9.30%, which is the average variation plus two standard deviations, would justify the establishment of 10% as the upper limit in cement-content variation between samples instead of the 12% limit previously used in the other phases of this investigation when the minus No. 30 material was used for the cement-content tests.

PART IV: DISCUSSION OF EVALUATION TEST PROCEDURES

27. Comments on the suitability of the test procedures selected in this investigation for evaluating concrete mixer performance are as follows:

a. Sampling. For evaluating mixer performance, concrete samples should be obtained from the first, middle, and last portions of the mixer discharge. In this investigation all of the samples were obtained after the batch had been discharged into the sampling container or containers.

b. Unit weight of air-free mortar. Since this test is not influenced by the effects of air content and percentage of coarse aggregate, it should provide a good indication of the distribution of the water, cement, and sand. The limit on maximum variation between samples as developed in this investigation appears to be 0.8%. This is in agreement with the findings reported by the Bureau of Reclamation, except that the Bureau uses two rather than three samples. This limit appears satisfactory for both 1-1/2- and 6-in. maximum size aggregate concrete.

c. Percentage of coarse aggregate. This test provides a measure of the distribution of the coarse aggregate in the concrete. Care must be taken to obtain representative samples of the concrete. A 0.25-cu-ft sample of 1-1/2-in. aggregate concrete appeared to be adequate; however, the 6-cu-ft field sample of 6-in. aggregate concrete gave less variation in percentage of coarse aggregate than did the 2-cu-ft laboratory samples. This could have resulted from the use of the different-size mixer. The maximum variation (average variation plus two standard deviations (S)) between samples was found to be 4.03% for the 1-1/2-in. maximum size aggregate, but a value of 5% was used in this study. Since this was in agreement with the limit of 5% set by the two-sample procedures of the Bureau of Reclamation, it is believed that 5% should be used. Although the limit derived from the 6-in. aggregate concrete mixed in the laboratory 10-S mixer was 13%, the value obtained from the 6-in. aggregate concrete mixed in the 2-cu-yd field mixer was within the 5% limit. Thus, the 5% value appears to be suitable for all concrete mixtures containing both 1-1/2- and 6-in. maximum size aggregate.

d. Water content of fresh mortar. This test, simple and easy to run, apparently provides a good indication of the dispersion of the water in the concrete. The limit of variation established for this test was 5%.

e. Cement content of dry mortar. Accurate determination of cement content would be one of the best tests of mixer performance. However, difficulties were encountered at first

> in obtaining accurate determinations. It was believed that, if the cement content was determined on a weight basis as a percentage of the dry mortar sample the accuracy would be improved. Strict adherence to the procedures specified for the preparation and testing of the samples is necessary. It is believed that the revised method of testing for cement content given in detail in Appendix A is reliable. The limit of variation set for cement content using this revised procedure is 10%.

28. Evaluation studies of mixer performance have also been made by the Ohio River Division Laboratories,[16] and resulted in the following recommendations: (a) Three samples should be taken, one from the front, middle, and back of the batch; (b) tests of unit weight of air-free mortar, percentage of coarse aggregate, water content of mortar, cement content of mortar, and air content of mortar should be made. These recommendations are in close agreement with WES recommendations except for the air content of mortar test which WES omitted.

PART V: CONCLUSIONS

29. Based on the results of this investigation, it is concluded that:

a. The procedures suggested herein will furnish reliable information as to the uniformity of mixing of concrete materials by a concrete mixer.

b. Three samples taken from the first, middle, and last portions of the batch as it is discharged from the mixer are adequate.

c. Tests to determine unit weight of the air-free mortar, the percentage of coarse aggregate in the concrete, the water content of the fresh mortar, and the cement content of the dry mortar will provide information as to the distribution of the component parts of the concrete batch.

d. From the work reported herein, it seems that maximum variations from the average for each test should be:

(1) Unit weight of air-free mortar, 0.8%.

(2) Percentage of coarse aggregate, 5%.

(3) Water content of mortar, 5%.

(4) Cement content of dried mortar,* 10%.

e. It is recommended that the complete evaluation be used when a mixer is first put into operation on a job and at any time when there is a question as to its efficient mixing operation. It is, however, suggested that routine checks be made at frequent intervals using only the unit weight of air-free mortar and the per cent of coarse aggregate test as these values will indicate the uniformity of the aggregate, cement, sand, and water or the necessity for a full evaluation.

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* Based on the cement-content test described in Appendix A.

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2. American Society for Testing Materials, "Proposed method for analyzing fresh mortar." American Society for Testing Materials Bulletin, No. 154 (October 1948), p 21.

   Method suggests masonry mortar test involving centrifuging the minus 200-sieve-size material. Similar to reference 1.

3. Andersen, J., Bredsdorf, P., Krarup, H., Malmstedt-Andersen, K., Nerenst, P., and Plum, N. M., Testing of Eleven Danish Concrete Mixers. Copenhagen, Denmark, 1951.

   One of the most complete test programs found. The methods used included crushing strength (cylinders and cubes), workability by the Vebe apparatus, and an analysis of the concrete mixture for cement content, water content, and fine- and coarse-aggregate contents. Chemical methods were tried but were found too time-consuming; pycnometer was used to determine volume, and sieves were used for breakdown. This report lists 111 methods.

4. "Checking concrete water-cement ratio." Engineering, vol 175, No. 4554, London, England (May 8, 1953), p 608. Also see Concrete and Constructional Engineering, vol 46 (Dec 1951), p 374, and Pit and Quarry, vol 46 (1954), pp 158-160, 164 of February 1954 issue.

   Method describes a probe-type meter. Procedure is to insert probe in freshly mixed concrete; a built-in vibrator brings mortar to the surface, and the water content of the mortar is determined by its electrical conductivity.

5. Davis, O. L., "Analysis of variance," in Statistical Methods in Research and Production (Hafner Publishing Co., New York, N. Y., 1958), Chap. 6.

6. Droege, W. H., "Dissect your fresh concrete." American City, vol 41, No. 12 (1946), and Chemical Abstracts, vol 42 (1948), p 3548.

   Method uses drying and sieving.

7. Dunagan, W. M.. "A method of determining the constituents of fresh concrete." Proceedings, American Concrete Institute, vol 26 (1930), pp 202-221.

   The method first used by the Bureau of Reclamation involving special apparatus to secure the weight of concrete sample immersed in water. The concrete is sieved to provide mixture breakdown. Discussion in Proceedings, American Concrete Institute, vol 26 (1930), pp 680-687.

Comments by Hughes, Ross, Griesenauer, and Fizol, who in general approved, and Fertin, who did not approve of the test method.

8. Griesenauer, G. J., "A substitute for the compression test of concrete." Engineering News-Record, vol 103 (1929), pp 846-847.

A sieving test to determine the constituent parts of a mixture.

9. Harrison, J. L., "Effect of the length of the mixing period on the quality of the concrete mixed in standard pavers." Public Roads, vol 9 (1928), pp 93-111.

An investigation of mixing time using slump, cylinder results and cement-water ratio; samples from the middle of the batch. Harrison checked Abrams' (see reference 1) results on a decrease in crushing strength with an increase in mixing time from 1 to 2 min.

10. Hime, W. G., and Willis, R. A., "Method for determination of cement content of plastic concrete." American Society for Testing Materials Bulletin, No. 209 (October 1955), pp 37-43.

Outlines a method of heavy-liquid-media separation for the determination of cement and fine sand (-100) in a sample of fresh concrete. This article lists 34 references concerning the subject in general. For the most part, all the procedures are similar and use one of the methods listed below:

a. Dunagan type, specific gravity, unit weight.
b. Sieve analysis or wash over a sieve.
c. Testing of hardened cast specimen.
d. Workability tests.
e. Drying tests.
f. Hydrometer analysis.
g. Chemical analysis.
h. Centrifuging to separate materials into fractions of different specific gravities.
i. Electrical methods of conductivity.
j. Air content.
k. Air-free density.

11. Kirkham, R. H. H., "Testing of concrete mixers." The Engineer, vol 195 (January-June 1953), pp 232-235, pp 286-288, pp 321-323, pp 341-343.

An adaptation of Dunagan's method.

12. Meyer, Erik V., "Determination of the mixing ratio for unset concrete or mortar by physical investigation." Beton-Tekn, vol 8 (1942), pp 125-131, and Chemical Abstracts, vol 38 (1944), p 4399.

Describes a combination chemical (NH_4Cl) and sieving method.

13. Murdock, L. J., "The efficiency of concrete mixing plant." Institution of Civil Engineers Journal, vol 31, No. 1, London, England (November 1948), pp 56-81.

Method uses sieving, drying, and chemical analysis.

14. Patch, O. G., "Mixer efficiency or mortar-mix tests." Journal, American Concrete Institute, vol 10, No. 3 (6 January 1939), pp 173-178.

Program of tests for mixers at Coulee Dam. Test method includes unscrambling by washing and immersion, similar to Dunagan's method. This was one of the Bureau of Reclamation Designation 26 tests. The discussion by Mr. Abrams is quite critical of the test method and the sampling procedure. The author's closure and one by Arthur Ruettger attempt to answer Mr. Abrams' objections.

15. "Portable equipment developed for large concrete samples." Engineering News-Record, vol 131 (1943), p 892.

Describes a large Dunagan apparatus.

16. U. S. Army Engineer Division, Ohio River, CE, Mixer Performance Study, Clinton County Air Force Base, by I. Narrow. Mariemont, Ohio, October 1959.

17. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements. Vicksburg, Miss.

18. U. S. Bureau of Reclamation, Concrete Manual, 2d ed. 1939.

Page 196: "Variations of over 10 per cent in either the sand-cement ratio or the water-cement ratio as determined by testing three distributed samples...should be corrected by blade change or batching improvement or by increase in the mixing time."

In Designation 26 the following procedure is used:

a. Samples obtained from different parts of the mixer.
b. Apparent water:cement and sand:cement ratios determined.
c. Three samples obtained.
d. Screened over No. 4 sieve.
e. Minus No. 4 weight in air and weight in water determined.
f. Specific gravity of sand and cement and percentage sand determined.

19. __________, Concrete Manual, 4th ed. October 1942.

Page 252, the following are recommended:

a. Test of unit weight of air-free mortar should be made.
b. Coarse aggregate, larger than 3/4 in., in the last 10% of the batch discharge should not differ by more than 20% by weight or volume from that in the first 10%.

In "Mortar Test," page 432, the following procedures are recommended:

a. Obtain three samples large enough to yield 1000 g of mortar.
b. Sieve samples on a No. 4 sieve.
c. Weigh samples and determine volume (pycnometer).
d. Calculate the specific gravity of the air-free mortar.

e. Variability is equal to the difference between maximum and minimum values. Results should not vary more than 2.3 lb per cu ft.

In "Discussion," page 437: Based on several hundred tests, it was apparent that the unit weights of the mortars reflect the adequacy of mixing as well as variations in ratios.

20. U. S. Bureau of Reclamation, Concrete Manual, 5th ed. September 1949.

Page 222: The same coarse aggregate specification as in reference 19.

Page 239: The same pycnometer method as in reference 19 but with the maximum allowable variation for a single batch of 2.3 lb per cu ft.

21. ________, Concrete Manual, 6th ed. 1955.

Page 213:

a. The unit weight of air-free mortar at the front and back of the mixer will not vary more than 0.8% from the average of the two mortar unit weights.
b. The weight of coarse aggregate retained on a No. 4 sieve in a cubic foot of concrete from the front and back of the mixer will not vary more than 5% from the average of the two weights of coarse aggregates.

Page 447, Method - Designation 26:

a. Use 1/4-cu-ft air meter for concrete containing 1-1/2-in. or smaller aggregate.
b. Obtain two samples.
c. Variations in mortar indicate the need for increased mixing time. Variations in weight of coarse aggregate indicate poor mixing design or worn blades.

Table 1

[illegible] Well-Mixed (Mixing [illegible]) Concrete

Containing 1-1/2-in. Maximum-Size Aggregate

[illegible]

Batch No.	Sample No.	Five Samples: Pressure Air Content %	Five Samples: Unit Weight Concrete lb/cu ft	Five Samples: Mortar:Coarse Aggregate Ratio	Five Samples: % Coarse Aggregate in Air-Content Container	Five Samples: Unit Wt of Air-Free Mortar lb/cu ft	Three Samples: Sample No.	Three Samples: % Coarse Aggregate in Air-Content Container	Three Samples: Unit Wt of Air-Free Mortar lb/cu ft
1	A	[illegible]	[illegible]	[illegible]	50.4	141.21	A	50.4	141.21
	[illegible]	[illegible]	[illegible]	[illegible]	50.4	[illegible]			
	C	[illegible]	[illegible]	[illegible]	51.8	[illegible]	C	51.8	141.[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	51.4	141.70			
	E	[illegible]	[illegible]	0.94	51.7	142.10	E	51.7	142.10
	Avg	[illegible]	147.01	[illegible]	51.1	141.71		51.3	141.76
	Max var, %	[illegible]	0.5	[illegible]	1.4	0.35		1.7	0.39
2	B	[illegible]	146.47	0.94	51.6	140.86			
	A	[illegible]	[illegible]	0.93	51.9	140.58	A	51.9	140.[illegible]
	E	4.7	[illegible]	0.94	51.7	140.76	E	51.6	140.76
	C	[illegible]	[illegible]	0.94	51.6	141.[illegible]	C	51.6	141.26
	D	4.7	146.88	0.89	[illegible]	140.89			
	Avg	[illegible]	146.19	0.93	51.9	140.87		51.7	140.87
	Max var, %	[illegible]	0.5	4.3	1.9	0.28		0.7	0.28
3	C	5.0	146.28	0.91	52.3	140.89	C	52.3	140.89
	D	4.8	146.68	0.86	53.7	140.42			
	A	4.7	146.68	0.92	52.0	140.92	A	52.0	140.92
	E	4.7	146.88	0.98	50.3	142.08	E	50.3	142.08
	B	5.3	145.87	0.94	51.4	141.42			
	Avg	4.9	146.68	0.92	51.9	141.15		51.5	141.30
	Max var, %	8.1	0.6	7.6	3.5	0.66		2.4	0.55
4	D	4.9	146.60	0.90	52.5	141.12			
	E	4.9	146.60	0.95	51.4	141.65	E	51.4	141.65
	B	5.2	145.83	0.99	50.3	141.58			
	A	4.9	146.44	1.00	50.1	141.92	A	50.1	141.92
	C	4.5	146.72	0.96	51.1	141.71	C	51.1	141.71
	Avg	4.9	146.44	0.96	51.1	141.60		50.9	141.76
	Max var, %	6.1	0.4	6.2	2.7	0.34		1.5	0.11
5	E	5.3	145.91	0.93	51.7	141.37	E	51.7	141.37
	C	5.4	145.47	0.96	51.0	141.17	C	51.0	141.17
	D	4.9	146.52	0.90	52.6	140.93			
	B	5.5	145.06	1.01	49.8	141.26			
	A	4.9	146.52	0.90	52.6	140.93	A	52.6	140.93
	Avg	5.2	145.90	0.94	51.5	141.13		51.7	141.16
	Max var, %	5.8	0.4	7.4	3.3	0.17		1.6	0.16
6	A	4.9	146.42	0.89	53.0	140.73	A	53.0	140.73
	B	5.2	145.87	0.98	50.4	141.59			
	C	5.0	146.07	1.00	50.1	141.56	C	50.1	141.56
	D	4.7	147.21	0.92	52.0	141.92			
	E	4.7	146.92	0.97	50.8	141.95	E	50.8	141.95
	Avg	4.9	146.52	0.95	51.3	141.55		51.3	141.41
	Max var, %	6.1	0.5	6.3	3.3	0.58		3.4	0.48
7	B	5.5	144.98	0.95	51.2	140.46			
	A	5.3	145.99	0.92	52.1	141.32	A	52.1	141.32
	E	5.0	146.44	0.93	51.8	141.44	E	51.8	141.44
	C	5.1	145.63	1.00	49.9	141.13	C	49.9	141.13
	D	4.7	146.88	0.88	53.1	140.80			
	Avg	5.1	145.98	0.94	51.6	141.03		51.3	141.30
	Max var, %	7.8	0.7	6.4	3.3	0.40		2.7	0.12
8	C	4.3	147.73	0.98	50.5	142.40	C	50.5	142.40
	D	4.4	147.53	1.01	49.8	142.63			
	A	4.4	147.29	1.03	49.3	142.43	A	49.3	142.43
	E	4.3	147.77	0.97	50.8	142.37	E	50.8	142.37
	B	4.3	147.89	0.98	50.6	142.67			
	Avg	4.3	147.64	0.99	50.2	142.50		50.2	142.40
	Max var, %	2.3	0.2	4.0	1.8	0.12		1.8	0.02
9	D	4.9	146.52	0.90	52.6	140.91			
	E	4.9	146.64	0.90	52.5	141.19	E	52.5	141.19
	B	5.2	145.67	0.95	51.4	140.78			
	A	5.1	146.03	1.02	49.6	141.97	A	49.6	141.97
	C	4.7	146.88	0.94	51.5	141.55	C	51.5	141.55
	Avg	5.0	146.35	0.94	51.5	141.28		51.2	141.57
	Max var, %	6.0	0.5	8.5	3.7	0.40		3.1	0.28
10	E	4.5	147.49	0.91	52.3	141.70	E	52.3	141.70
	C	4.4	147.65	0.91	52.3	141.74	C	52.3	141.74
	D	4.0	148.54	0.86	53.7	141.56			
	B	4.7	147.17	0.99	50.3	142.58			
	A	4.4	147.77	0.96	51.1	142.52	A	51.1	142.52
	Avg	4.4	147.72	0.93	51.9	142.02		51.9	141.99
	Max var, %	9.1	0.6	7.5	3.5	0.34		1.6	0.37
Grand avg	Max var, %	6.58	0.49	6.02	2.8	0.36		2.04	0.276
	Std dev, %	1.88	0.138	2.00	0.82	0.164		0.82	0.174
Grand avg + 2 std dev, %		10.34	0.77	10.02	4.44	0.688		3.68	0.624

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Table 2

Results of Tests of Poorly Mixed (Mixing Time, 15 sec) Concrete

Containing 1-1/2-in. Maximum Size Aggregate

Phase I, Laboratory Tests

Batch No.	Sample No.	Pressure Air Content %	Unit Weight Concrete lb/cu ft	Mortar: Coarse Aggregate Ratio	% Course Aggregate in Air-Content Container	Unit Weight of Air-Free Mortar lb/cu ft
11	A	5.0	146.48	0.99	50.3	142.19
	C	5.5	146.48	1.07	48.2	144.44
	E	4.5	147.29	0.72	58.3	138.19
	Avg	5.0	146.75	0.93	52.3	141.61
	Max var, %	10.0	0.37	22.6	11.5	2.4
12	C	4.6	147.29	0.82	54.8	140.38
	E	6.2	143.64	0.76	56.9	136.92
	A	3.8	149.72	0.96	51.1	144.35
	Avg	4.9	146.88	0.85	54.3	140.55
	Max var, %	26.5	2.21	12.9	5.9	2.7
13	E	4.8	147.29	0.70	58.8	138.80
	A	4.0	148.91	0.90	52.8	142.71
	C	4.5	144.45	0.77	56.1	133.68
	Avg	4.4	146.88	0.79	55.9	138.40
	Max Var, %	9.1	1.65	13.9	5.5	3.4
14	C	4.5	147.29	0.82	52.9	140.09
	A	3.5	148.50	0.95	51.3	141.24
	E	5.0	145.67	0.81	55.3	138.21
	Avg	4.3	147.15	0.86	53.2	139.85
	Max var, %	18.6	1.01	10.5	3.9	1.2
15	E	3.6	149.72	0.84	54.4	142.31
	C	4.2	146.88	0.83	54.6	138.59
	A	3.4	148.50	0.97	50.7	141.22
	Avg	3.7	148.37	0.88	53.2	140.71
	Max var, %	13.5	1.00	10.2	4.7	1.5
16	A	4.0	149.31	0.80	55.5	142.19
	E	4.6	147.29	0.77	56.3	139.58
	C	4.0	146.07	0.87	53.5	137.11
	Avg	4.2	147.56	0.81	55.1	139.63
	Max var, %	14.3	1.19	7.4	2.9	1.8

Table 1

Results of Tests of Concrete Containing 1 1/2-in. Maximum Size Aggregate Mixed for 45, 90, 120, and 240 Sec

Phase II, Laboratory Tests

Batch No.	Sample No.	Pressure Air Content %	% Coarse Aggregate: Air-Content Container Sample	% Coarse Aggregate: Total Sample	Unit Weight of Air-Free Mortar lb/cu ft	Water Content of Fresh Mortar %	% Cement Content by Wt of Dried Mortar
	Mixing Time, 45 sec						
17	A	2.9	[illegible]	46.00	141.77	11.2	30.8
	B	4.2	49.21	50.11	141.15	12.0	21.0
	C	5.1	54.05	55.79	140.51	11.8	21.4
	Avg	4.1	[illegible]	50.93	141.55	12.3	24.4
	Max var, %	29.1	8.27	9.54	1.62	7.1	[illegible]
18	B	4.5	50.24	52.32	142.47	11.3	26.5
	C	4.1	50.66	54.49	138.15	12.6	28.5
	A	3.8	43.35	45.16	145.22	10.4	21.0
	Avg	4.2	50.00	51.05	141.61	12.4	25.3
	Max var, %	9.5	17.13	18.36	2.55	16.1	17.0
19	C	4.7	52.66	57.59	138.12	14.1	27.8
	A	3.8	44.80	44.51	144.64	11.3	21.2
	B	4.2	45.00	48.51	141.29	12.3	26.2
	Avg	4.2	49.18	[illegible]	142.02	12.6	25.7
	Max var, %	11.9	15.21	[illegible]	2.75	13.5	9.7
20	B	4.7	42.25	45.66	143.28	12.0	20.7
	A	4.0	47.23	40.80	141.71	10.8	21.2
	C	5.6	62.05	61.40	136.20	11.8	26.6
	Avg	4.8	49.84	49.22	140.40	12.2	22.8
	Max var, %	16.7	26.49	27.00	4.42	13.1	16.7
21	C	4.7	55.28	56.91	138.89	14.2	31.0
	B	4.1	48.05	48.66	141.65	12.4	29.3
	A	4.0	40.46	42.05	146.04	10.2	20.1
	Avg	4.3	47.25	49.21	142.20	12.2	26.8
	Max var, %	9.3	16.97	15.05	2.78	16.4	25.0
22	A	4.1	41.04	41.02	145.15	10.4	24.8
	C	5.0	55.03	57.08	138.36	13.8	31.0
	B	4.4	[illegible]	50.44	142.00	13.0	29.2
	Avg	[illegible]	47.20	49.05	141.04	12.4	28.0
	Max var, %	11.1	14.67	16.11	2.45	16.1	11.4
	Mixing Time, 90 sec						
23	A	[illegible]	[illegible]	50.1	140.04	13.7	22.6
	B	4.7	[illegible]	52.2	140.59	13.6	24.0
	C	[illegible]	[illegible]	51.4	141.10	13.1	20.0
	Avg	[illegible]	[illegible]	51.2	140.58	13.5	22.2
	Max var, %	[illegible]	[illegible]	2.1	0.38	4.0	9.9
24	B	6.2	51.15	50.2	140.74	12.4	23.3
	C	5.6	50.45	49.5	141.60	13.0	23.3
	A	5.5	[illegible]	50.0	141.87	13.0	23.3
	Avg	5.8	50.82	49.6	141.33	12.8	23.3
	Max var, %	6.9	0.73	2.2	0.42	3.1	0.0
25	C	5.8	51.70	51.0	140.84	12.2	19.3
	A	4.6	50.03	49.0	142.66	14.0	25.2
	B	4.4	49.34	48.8	143.12	13.6	27.0
	Avg	4.9	50.02	49.6	142.21	13.3	23.8
	Max var, %	18.4	3.36	2.8	0.96	8.3	18.9
26	A	5.8	49.75	46.2	141.74	12.0	24.0
	B	4.5	49.47	49.3	142.62	13.4	24.6
	C	4.4	50.44	49.8	142.65	12.8	21.3
	Avg	4.9	49.89	48.4	142.34	12.7	23.3
	Max var, %	18.4	1.10	4.5	0.42	5.5	8.6
27	B	5.5	52.38	50.6	141.90	13.0	22.6
	C	4.8	52.37	51.1	141.42	13.2	24.6
	A	4.6	49.75	49.7	142.77	13.2	25.8
	Avg	5.0	51.50	50.5	142.04	13.1	24.3
	Max var, %	10.0	3.4	1.6	0.51	0.8	7.0
28	C	5.7	51.15	50.9	140.82	11.4	22.6
	A	3.8	48.26	48.5	143.37	13.0	27.0
	B	3.7	48.12	47.9	143.85	13.0	24.0
	Avg	4.4	49.18	49.1	142.68	12.5	24.5
	Max var, %	29.5	4.01	3.7	1.30	8.8	10.2
	Mixing Time, 120 sec						
29	A	4.8	50.86	50.1	141.38	12.9	24.0
	B	4.8	50.50	48.3	141.51	12.4	25.2
	C	4.8	49.82	50.0	141.49	12.7	25.8
	Avg	4.8	50.42	49.5	141.46	12.7	25.0
	Max var, %	0.0	1.2	2.6	0.09	0.2	4.0
30	B	4.7	48.92	47.9	141.97	11.4	22.0
	C	4.5	48.93	48.7	141.76	11.9	20.0
	A	4.1	50.10	52.3	142.44	11.5	21.3
	Avg	4.5	49.34	49.6	142.06	11.6	21.1
	Max var, %	4.4	1.5	5.4	0.27	2.6	5.2
31	C	4.3	50.51	50.6	141.90	12.2	21.3
	A	3.7	47.78	51.0	142.95	12.3	22.2
	B	4.0	49.07	48.5	142.15	11.6	21.3
	Avg	4.0	49.12	50.0	142.36	12.0	21.3
	Max var, %	7.5	2.8	3.0	0.41	3.3	8.6
32	A	4.5	49.20	51.0	142.74	11.2	22.6
	B	4.5	48.24	48.2	142.44	11.3	25.2
	C	4.5	46.43	47.1	142.49	11.2	24.0
	Avg	4.5	47.96	48.8	142.56	11.2	23.9
	Max var, %	0.0	3.2	4.7	0.13	0.9	5.4
33	B	4.5	46.30	47.5	142.55	10.8	24.6
	C	4.4	46.86	47.8	142.74	11.1	21.3
	A	3.8	49.62	50.3	142.80	11.4	22.0
	Avg	4.2	47.59	48.5	142.70	11.1	22.6
	Max var, %	9.5	4.3	3.7	0.11	2.7	8.8
34	C	4.4	46.29	49.1	141.61	11.6	25.2
	A	4.2	49.07	51.3	142.69	12.0	27.7
	B	4.4	46.43	46.9	142.21	11.0	25.8
	Avg	4.3	47.26	49.1	142.18	11.8	26.2
	Max var, %	2.3	3.00	4.5	0.40	1.7	5.7
	Mixing Time, 240 sec						
35	A	4.8	50.9		140.63	12.9	17.5
	B	5.1	50.0		139.73	13.0	17.5
	C	4.8	52.7		139.79	13.0	16.2
	Avg	4.9	51.20		140.05	12.97	17.07
	Max var, %	4.1	2.93		0.41	0.54	5.10
36	C	6.2	55.3		138.65	13.1	18.1
	B	6.8	52.6		138.73	13.0	17.5
	A	6.3	53.8		138.55	13.1	18.7
	Avg	6.4	53.90		138.64	13.07	18.10
	Max var, %	6.2	2.40		0.06	0.54	3.31
37	A	6.5	50.0		140.30	12.7	22.0
	B	6.6	50.3		140.07	12.8	23.3
	C	6.8	52.7		138.70	12.3	19.3
	Avg	6.6	51.0		139.69	12.60	21.53
	Max var, %	3.0	3.32		0.71	2.38	10.36
38	C	5.7	51.5		140.65	12.5	15.5
	B	5.6	50.9		140.87	11.9	16.8
	A	5.6	48.4		141.80	12.4	17.5
	Avg	5.6	50.27		141.11	12.27	16.60
	Max var, %	1.8	3.72		0.49	3.02	6.63
39	A	5.4	49.8		141.90	13.4	29.7
	B	5.6	49.1		141.11	12.7	28.4
	C	5.6	51.4		140.79	12.7	25.8
	Avg	5.5	50.1		141.27	12.93	27.96
	Max var, %	1.8	2.59		0.45	3.63	7.73
40	C	4.9	48.1		142.51	11.8	25.2
	B	4.8	47.7		142.77	12.0	26.4
	A	4.8	46.2		143.38	12.1	22.6
	Avg	4.8	47.33		142.89	11.97	24.73
	Max var, %	2.1	1.63		0.36	1.42	8.01
Grand avg	Max var, %		2.80		0.41	1.92	6.96
	Std dev, %		0.72		0.2123	1.30	2.52
Grand avg + 2 std dev, %			4.26		0.835	4.52	12.00

Table 4

Results of Tests of Concrete Containing [illegible], Maximum Size

Aggregate Mixed for 15 and 240 Sec

Phase III, Laboratory Tests

Batch No.	Sample No.	Pressure Air Content %	% Coarse Aggregate Total Sample	Unit Wt of Air-Free Mortar lb/cu ft	Water Content of Fresh Mortar %	% Cement Content by Weight of Dried Mortar
			Mixing Time, 15 sec			
41	A	4.6	66.6	140.81	12.5	13.5
	B	4.4	64.9	142.82	10.3	12.2
	C	4.7	80.1	121.49	11.1	16.8
	Avg	4.6	70.5	135.05	11.3	14.2
	Max var, %	4.3	13.5	10.0	10.6	10.3
42	B	3.9	66.4	142.65	11.5	14.8
	C	3.8	71.2	142.32	11.3	14.2
	A	5.0	69.8	141.76	11.8	12.2
	Avg	4.2	69.1	142.24	11.5	13.7
	Max var, %	19.0	4.0	0.3	2.6	10.9
43	C	5.5	64.7	137.78	13.7	17.5
	A	5.5	81.9	136.75	10.6	12.2
	B	3.0	69.9	141.61	12.1	21.3
	Avg	4.7	72.2	138.71	12.1	17.0
	Max var, %	30.2	13.5	2.1	13.2	28.2
44	A	4.5	78.2	144.17	11.2	14.8
	B	5.5	64.3	139.04	12.2	10.3
	C	4.4	66.5	139.91	11.2	11.0
	Avg	4.8	69.6	141.04	11.5	12.0
	Max var, %	14.6	12.2	2.2	6.1	23.3
45	B	6.2	65.2	138.06	13.4	12.2
	C	4.4	66.8	138.06	12.3	15.5
	A	5.7	76.1	126.46	8.3	16.8
	Avg	5.4	69.3	134.19	11.3	14.8
	Max var, %	18.5	9.7	5.8	26.5	17.6
46	C	5.8	64.3	138.04	11.7	7.0
	A	3.4	75.8	111.86	9.0	22.6
	B	4.3	67.9	141.18	12.5	13.5
	Avg	4.5	69.3	130.36	11.1	14.4
	Max var, %	28.9	9.4	14.2	18.9	56.9
			Mixing Time, 240 sec			
47	A	4.7	71.6	140.92	11.3	11.6
	B	4.2	68.4	141.56	11.1	12.9
	C	4.4	68.5	141.52	11.6	15.5
	Avg	4.4	69.5	141.33	11.3	13.3
	Max var, %	6.8	3.0	0.29	2.6	16.5
48	B	4.7	67.5	141.93	12.2	14.8
	C	4.4	66.5	141.77	12.8	13.5
	A	4.2	70.4	142.16	13.0	14.8
	Avg	4.4	68.1	141.95	12.7	14.4
	Max var, %	6.8	3.4	0.15	3.9	6.2
49	C	5.0	70.6	141.33	13.3	16.8
	A	4.6	71.4	141.66	13.5	16.8
	B	4.6	64.4	142.01	12.7	16.8
	Avg	4.7	68.8	141.67	13.2	16.8
	Max var, %	6.4	6.4	0.24	3.8	0.0
50	A	4.7	75.8	140.30	13.7	15.5
	B	4.5	64.3	141.37	12.8	17.5
	C	4.3	65.6	141.24	13.4	17.5
	Avg	4.5	68.6	140.97	13.3	16.8
	Max var, %	4.4	10.5	0.48	3.8	7.7
51	B	4.5	66.7	140.94	13.6	16.8
	C	4.3	66.6	141.74	13.0	15.5
	A	3.8	74.2	141.13	13.9	16.2
	Avg	4.2	69.2	141.27	13.2	16.2
	Max var, %	9.5	7.2	0.33	3.0	4.3
52	C	4.3	64.8	140.64	13.1	16.8
	A	4.2	75.8	141.76	12.6	17.5
	B	4.0	67.2	141.11	12.3	18.1
	Avg	4.2	69.3	141.17	12.7	17.5
	Max var, %	4.8	9.4	0.42	3.1	4.0
Grand avg	Max var, %	6.45	6.650	0.32	3.3660	6.450
	Std dev, %	1.922	3.054	0.0881	0.3056	2.157
Grand avg + 2 std dev, %		10.294	12.758	0.50	3.9772	10.764

Table 5

Results of Tests of Concrete Containing 6-in. Maximum Size Aggregate Mixed for 15, 120, and 240 Sec, Phase IV Field Test

Batch No.	Sample No.	Pressure Air Content %	% Coarse Aggregate Total Sample	Unit Wt of Air-Free Mortar lb/cu ft	Water Content of Fresh Mortar %	% Cement Content by Weight of Dried Mortar
			Mixing Time, 15 sec			
53	A	4.2	70.9	140.63	11.4	14.2
	B	4.4	64.7	140.51	12.0	14.2
	C	3.0	62.9	144.75	8.1	11.0
	Avg	3.9	66.2	141.96	10.5	13.1
	Max var, %	23.1	7.1	2.0	22.9	16.0
54	B	2.8	68.6	138.80	13.3	20.6
	C	4.4	61.2	138.94	13.0	16.2
	A	8.5	62.6	132.04	8.0	9.0
	Avg	5.2	64.1	136.59	11.4	15.3
	Max var, %	63.5	6.9	3.3	29.8	41.2
55	C	4.8	70.7	134.54	14.5	11.6
	A	4.7	60.6	144.27	11.9	12.2
	B	7.5	63.2	140.43	8.5	7.8
	Avg	5.7	64.8	139.75	11.6	10.5
	Max var, %	31.6	9.0	3.7	26.7	25.7
			Mixing Time, 120 sec			
56	A	5.2	63.0	140.96	12.0	14.2
	B	5.3	63.1	141.10	11.6	12.9
	C	5.0	66.6	140.85	12.0	16.2
	Avg	5.2	64.2	140.97	11.9	14.4
	Max var, %	3.8	3.6	0.09	2.3	12.5
57	B	3.9	69.9	144.63	10.3	12.2
	C	3.5	67.2	144.66	10.2	13.5
	A	3.7	69.1	144.75	9.6	14.2
	Avg	3.7	68.7	144.68	10.0	13.3
	Max var, %	5.4	2.2	0.05	4.3	8.3
58	C	4.6	69.0	138.90	12.3	14.2
	A	5.0	63.7	140.33	12.2	13.5
	B	4.9	69.0	139.27	12.4	17.5
	Avg	4.8	67.2	139.50	12.3	15.1
	Max var, %	4.2	5.3	0.59	0.8	15.9
			Mixing Time, 240 sec			
59	A	3.2	64.6	138.95	13.2	14.2
	B	3.4	64.9	140.06	12.5	14.8
	C	3.4	66.7	140.53	12.0	15.5
	Avg	3.3	65.4	139.85	12.6	14.8
	Max var, %	3.0	2.0	0.64	4.8	4.7
60	B	4.5	65.1	139.56	11.7	15.5
	C	4.7	65.7	140.06	11.7	14.2
	A	4.2	62.7	140.25	12.2	14.8
	Avg	4.5	64.5	139.96	11.9	14.8
	Max var, %	6.7	2.8	0.29	2.5	4.7
61	C	5.0	66.9	141.04	11.7	14.2
	A	4.5	66.2	139.42	12.1	15.5
	B	4.9	67.1	140.68	12.0	14.2
	Avg	4.8	66.7	140.38	11.9	14.6
	Max var, %	6.2	0.7	0.68	1.7	6.2

Table 6

Phase V Test Results for Well-Mixed Concrete (Mixing Time, 240 sec) Containing 1-1/2- and 6-in. Maximum Size Aggregate (Revised Cement-Content Test)

Batch No.	Sample No.	Aggregate Size, in.	Cement Content bags/cu yd	% Cement Content by Weight of Dried Mortar
62	A	1-1/2	4	21.6
	B			25.4
	C			23.2
	Avg			23.40
	Max var, %			8.55
63	A	1-1/2	5	26.2
	B			26.0
	C			24.2
	Avg			25.47
	Max var, %			4.99
64	A	1-1/2	5.5	26.5
	B			29.6
	C			27.3
	Avg			27.80
	Max var, %			6.47
65	A	1-1/2	6	27.9
	B			29.2
	C			29.9
	Avg			29.00
	Max var, %			3.79
66	A	6	2	12.6
	B			13.6
	C			14.2
	Avg			13.47
	Max var, %			6.46
67	A	6	2.5	16.4
	B			16.9
	C			16.7
	Avg			16.67
	Max var, %			1.62
68	A	6	3	18.2
	B			18.3
	C			17.1
	Avg			17.87
	Max var, %			4.31
69	A	6	4	25.3
	B			27.9
	C			26.6
	Avg			26.60
	Max var, %			4.89
Grand avg	Max var, %			5.14
	Std dev, %			2.08
Grand avg + 2 std dev, %				9.30

CRD-C 55-61

METHOD OF TEST FOR CONCRETE MIXER PERFORMANCE

Scope

1. This method outlines procedures for the evaluation of the effectiveness of a concrete mixer in mixing concrete by testing samples of the concrete for water content, cement content, unit weight of air-free mortar, and coarse aggregate content.

Apparatus and Materials

2. The apparatus and materials shall consist of the following:

(a) Concrete Mixer.- The concrete mixer to be evaluated.

(b) Air Meter.- An apparatus complying with the requirements of CRD-C 41 for determining the air content of freshly mixed concrete by the pressure method.

(c) Scales or Balances.-Scales and balances complying with the applicable provisions of CRD-C 512 and having capacities of 1000 lb, 2 kg, and 25 g, with an accuracy of 0.05% for any weight up to the listed capacity.

(d) Centrifuge.- A centrifuge complying with the applicable requirements of CRD-C 72.

(e) Drying Apparatus.- A hot plate capable of heating to at least 200 C, a drying pan, and a spatula.

(f) Sieving Apparatus.-A mechanical sieve shaker and sieves for sieving the concrete; the sieves shall conform to the requirements of CRD-C 102.

(g) Heavy Medium.-A liquid having a specific gravity of approximately 2.95 (1, 1, 2, 2 -tetrabromoethane is satisfactory).

(h) Mortar and Pestle.- A mortar and pestle made of material having a specific gravity less than 2.85.

(i) Sampler.- A suitable sampler to obtain representative samples.

Samples

3. Three samples shall be taken to represent the first, middle, and last portions of the batch discharged from the mixer. The sample size shall, in general, be as follows:

Maximum Nominal Size of Concrete Aggregate in.	Approximate Size of Each of Three Samples cu ft
3/4	0.50
1-1/2	0.75
3	1
6	3

Procedures

4. Sample Preparation.- (a) Weigh each of the three samples of freshly mixed concrete, and for concrete mixtures containing aggregate larger than 1-1/2 in. perform a preliminary mechanical sieving in order to obtain approximately 75 lb of material passing the 1-1/2-in. sieve for use in determining the unit weight of air-free mortar. For concrete mixtures containing no aggregate particles that would be retained on the 1-1/2-in. sieve, use the sample as obtained.

(b) Take approximately 25 lb of the concrete containing no aggregate particles that would be retained on the 1-1/2-in. sieve representing each of the three samples of the mixture, and mechanically sieve each over a dampened No. 4 sieve for 5 min. Use the material passing the No. 4 sieve for water-content and cement-content tests.

(c) In both of the sieving operations, care should be taken not to overload the test sieve; this can be done by using coarser sieves above the test sieve. The sampling and testing of the three samples should be conducted with as little a time lag as possible since the results are significantly affected by the time of testing.

Unit Weight of Air-free Mortar

5. (a) The unit weight of air-free mortar is determined on the portion of each of the three samples passing the

1-1/2-in. sieve. First, consolidate the concrete in the air-content test container and obtain the weight for that volume; then determine the air content on the same sample using the procedure given in CRD-C 41. Wash the entire air-content test sample over a No. 4 sieve, and obtain the saturated surface-dry weight of the retained aggregate.

(b) The unit weight of air-free mortar is calculated as follows:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G \times 62.3}\right)}$$

where:

M = unit weight of air-free mortar, lb/cu ft,
b = weight of concrete sample, lb,
c = saturated surface-dry weight of aggregate retained on the No. 4 sieve, lb,
V = volume of the air-content test container, cu ft,
A = air content of sample tested, %, and
G = specific gravity of the coarse aggregate.

Percentage of Coarse Aggregate in Sample

6. (a) In addition to the sample from the air-content test container, which has been previously washed over a No. 4 sieve, wash all of the original concrete for each of the three samples (including that portion passing the 1-1/2-in. sieve previously sieved out) over a No. 4 sieve and obtain the total saturated surface-dry weight of material retained on the No. 4 sieve.

(b) For concrete containing large aggregate it may be desirable, after the total weight retained on the No. 4 sieve has been obtained, to sieve the retained material over the 1-1/2- and 3-in. sieves to obtain further information concerning the distribution of the coarse aggregate for each of the three samples.

(c) The percentage of coarse aggregate retained on each of these sieves is obtained by dividing the saturated surface-dry weight of the material retained on each sieve by the weight of the original sample of the freshly mixed concrete as obtained from the mixer discharge.

Water Content

7. (a) Using that portion of the mixture passing the No. 4 sieve for each of the three samples, weigh out two 500-g fractions into pans and dry on the hot plate for at least 15 min after the material appears to be thoroughly dry, being careful to prevent any loss of solid material from the pans during drying.

(b) Upon completion of the drying, again weigh the samples to the nearest 0.1 g and determine water contents by the following formula:

$$P = \frac{500 - W}{500} \times 100$$

where:

P = water content of sample, %, and
W = weight of the dried sample, g.

(c) The water content reported shall be the average of the two determinations.

Cement Content

8. (a) Combine each set of the two individual dried samples from the water-content determination, stir thoroughly until well mixed, and quarter the material to obtain two 30-g representative fractions. Pulverize these 30-g fractions until each of them completely passes a No. 16 sieve. Take a 20-g portion from each and pour these separately into two 40-ml centrifuge tubes. To each add approximately 20 ml of 1,1,2,2-tetrabromoethane (specific gravity, 2.95) and stir until all the material is wetted; then add more 1,1,2,2-tetrabromoethane, bringing the volume up to 40 ml.

(b) Put the tubes in the centrifuge, turn it on and allow it to build up an RCF of 190, and maintain this force for 3 min; then cut off the power. After the tubes have stopped revolving, rotate each of them 180 degrees and stir the top layer of solids. Then turn on the centrifuge and allow it to build up an RCF of 525, and maintain

this force for 4 min. Stop the centrifuge and rotate the tubes 180 degrees, stir the top layer of solids, and again centrifuge as before at an RCF of 525 for 4 min.

(c) Stop the centrifuge, remove tubes, place them in a rack, and allow suspended particles in the tube to settle for 5 to 10 min. Then with a spatula puncture the layer of floating solids in each tube, pour this layer and any of the heavy liquid which pours with it into a beaker containing approximately 75 ml of acetone, being careful not to allow any of the heavier solids from the bottom of the tube to be included in the pouring. With the spatula, carefully transfer to the beaker any of the lighter solids which may remain on the inside or outside of the tube after pouring. Vigorously stir the acetone containing the solids for 5 to 10 sec; then allow the solids to settle out for 40 sec; carefully decant off the acetone; add approximately 50 ml acetone to the solids left in the beaker; stir 5 to 10 sec; allow the solids to settle out for 20 sec; decant off the acetone; pour approximately 50 ml more acetone over the solids; stir vigorously 5 to 10 sec; allow the solids to settle out for 20 sec; and decant off the acetone. Dry the solids then left in the beaker on a hot plate or in an oven; then cool and weigh to the nearest 0.01 g. There will be two weights of material having a specific gravity less than 2.95 for each of the three samples from each mixer test.

(d) The cement content of the dried concrete finer than the No. 4 sieve for each of the centrifuged samples, tested as indicated in Paragraph 8(a) through (c), shall be calculated as follows:

$$C = \frac{20 - F}{20} \times 100$$

where:

C = cement content of the dried concrete finer than the No. 4 sieve, %, and

F = weight of the minus 2.95 specific gravity solid material separated from the 20 g of minus No. 16 pulverized dried concrete, g.

Report

9. (a) In preparing the report on evaluation of the performance of the mixer under test, the results for each of the three samples for each test should be averaged and the percentage maximum variation from this average reported. This maximum variation in percentage should be determined for each of the tests.

(b) The report shall include the following:

(1) Name of manufacturer of mixer.

(2) Type and capacity of mixer.

(3) Mixing time for each batch of concrete tested.

(4) Complete data concerning the mixture proportions, including materials used and batch weight.

(5) Weight of each of the three concrete test samples from each batch tested.

(6) Average cement content of dried mortar to the nearest 0.1% by weight for each of the three test samples.

(7) Average water content of mortar to the nearest 0.1% by weight for each of the three test samples.

(8) The unit weight of air-free mortar to the nearest 0.1 lb per cu ft for each of the three test samples.

(9) Total amount of coarse aggregate to the nearest 0.1% by weight for each of the three test samples.

(10) The maximum variation from the average for each test, for cement content, water content, air-free unit weight of mortar, and coarse-aggregate content.

(c) The performance of a given concrete mixer as used for mixing a given batch of concrete for a given mixing time may be evaluated from the degree of variation reported under item 9(b)(10) above.